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Final Technical Report

ISTP Solar Maximum Extended Science Program

PI: Maha Ashour-Abdalla

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We have studied the entry of solar energetic particles (SEPs) into the magnetosphere by following particles in the time dependent magnetic and electric field from global magnetohydrodynamic (MHD) simulations of the magnetosphere. The MHD simulations can either be for idealized interplanetary magnetic field (IMF) conditions, or for upstream conditions measured by spacecraft. An important part of the analysis is understanding the response of the magnetosphere to the IMF conditions.

In the idealized case, the MHD simulation included a steady interplanetary magnetic field (IMF) B_x, velocity and density, while the B_y and B_z components were varied from southward IMF to dawnward and finally to northward IMF. We launched more than ten million protons, as well as about 1 million ^{3}He ions and a few thousand electrons upstream of the magnetosphere into the solar wind. They were initialized using a kappa distribution, which is a power law distribution with a power law coefficient of 1.5 at high energies. The particles had energies between 0.1 and 50 MeV. The particles were run in time dependent MHD fields that were advanced in time as the particles moved through the system.

The magnetopause and bow shock prevented most particles from entering the magnetosphere for all the IMF orientations investigated. During southward IMF, however, there was significant penetration of protons into the inner magnetosphere such that the flux of particles there became comparable to the solar wind. . Particles entering the magnetosphere sometimes became quasi-trapped and began drifting around the Earth. During southward IMF the protons entered mainly on the front side of the magnetosphere, often through the northern cusp. Ions with energies greater than about 10 MeV could directly penetrate the magnetosphere because of their large Larmor radii, while lower energy ions moved along open field lines into the magnetosphere. Ions were often were non-adiabatic, particularly when they crossed the magnetosphere. Ions also were observed becoming non-adiabatic as they made the transition to trapped trajectories.

During dawnward IMF open field lines extended through the dawn flank. This defined the primary entry region for the protons for this interval. The population of the inner magnetosphere diminished during dawnward IMF. During northward IMF the population of the inner magnetosphere increased briefly because of particles in the southern cusp region but then decreased to the lowest level seen in the calculation, but no particles became trapped. Particles observed on trapped trajectories during this interval had entered the magnetosphere earlier. For a steady proton source the omnidirectional proton fluxes in the inner magnetosphere varied by a factor of 100 as the IMF changed [*Richard et al.*, 2001a, 2002a]

The precipitation rate at the inner boundary followed the trend of the amount of open flux; that is more during southward IMF, an intermediate amount during dawnward IMF, and a relatively small amount during northward IMF. Because their initial energies were large compared to the cross magnetospheric potential, particle energization was not important except for particles. Trapped particles could be energized as the magnetic field changed.

In the idealized MHD simulation the magnetosphere was slowly varying, but not completely steady. To examine the applicability of the results for steady IMF conditions, we examined particle motion in time independent MHD fields (snapshots of the time dependent results). The time independent results were similar to the time dependent results for southward and dawnward IMF with some decrease in magnetospheric penetration. For northward IMF the calculations revealed that few particles became quasi trapped during this interval. The behavior of ^3He ions was similar to that of protons but they penetrated the magnetosphere at a lower. Electrons for the most part moved along field lines and but occasionally experienced non-adiabatic behavior [*Richard et al.*, 2001b]

We also simulated and analyzed a magnetic storm interval. We used a global MHD simulation to model the magnetic storm observed on May 4, 1998. During that day, solar wind velocity and density were extremely high, resulting in an unusually high solar wind dynamic pressure with numerous pulses over 20 nPa, the largest peak reaching about 60 nPa. The high strong solar wind dynamic pressure compressed the magnetosphere, causing the Polar spacecraft to cross the dayside magnetopause well inside the geosynchronous orbit and to experience two brief excursions into the solar wind. We used simultaneous solar wind ions and the IMF measured by the Wind spacecraft 240 R_E upstream, as driving input for the

MHD simulation. Comparison between time series from the simulation with measurements from the Polar and Geotail spacecraft revealed a good agreement. Other storm interval studies showed that the magnetospheric current systems were radically altered by compression of the magnetosphere and from the effect of large values of the southward IMF [*El-Alaoui et al.,* 2002].

For lower energy particles, magnetospheric electric fields were critical in accelerating particles [*Walker et al.,* 2002; *Schriver et al.,* 2001, 2002a], and during some intervals, ions could evidently be accelerated to more than 40 keV along field lines [*Richard et al.,* 2002b].

Publications

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Patents and Inventions

No Patents or Inventions resulted from this research project.